Catadioptric Dielectric Lens for Imaging Applications

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***Abstract*—The design and characterization results of a novel catadioptric dielectric lens are presented. Although being electrically small, the lens provides a focus in the close vicinity which makes it suitable to be used in microwave and terahertz systems. Several lenses of different dielectric materials and dimensions have been fabricated. A simple backscattering measurement method has been implemented in order to determine the focusing property of the lens.**

I. INTRODUCTION

THE rapid advancements in microwave and terahertz systems and components have paved the way for numerous applications [1] such as imaging, object investigation, nondestructive testing, RFID, security screening and biomedical applications. For many applications the electromagnetic beams are required to be collimated and focused to attain higher resolution. Because of low feed loss, ease of construction, and overall size reduction, lens-antenna or detector-lens configurations are an attractive solution for millimeter and sub-millimeter wave technologies [2]. However, the existing dielectric lenses are not capable of creating any focus.

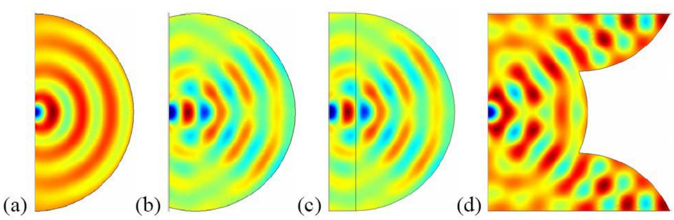

Fig. 1: Electric field distribution at 50 GHz in the (a) hemispherical, (b) elliptical, (c) extended hemispherical and (d) catadioptric lens. The dielectric constant of the lenses is $\varepsilon_r = 11.7$ and the lenses are of 16 mm diameter.

The proposed catadioptric dielectric lens provides an alternative solution to be used as a focusing element. The lens is scalable and provides greater ease of system integration. Radiating elements and sensors can be physically coupled to the catadioptric lens in order to achieve short-range focusing ability. The lens consists of a hemispherical part with a "horn-like" extension on top of it, as shown in Fig. 1(d). This catadioptric portion causes total internal reflection, which in turn creates the focus point. Fig. 2 shows the simulated Poynting vector plot and the focus point at ~50 GHz where the catadioptric lens (diameter = 2.6 λ_{lens}) was fed by a circular waveguide. The design, working principles and characterization results of the catadioptric lens have already been reported [3]. However, the current research focus concentrates on more extensive characterization and implementing the lens in various setups.

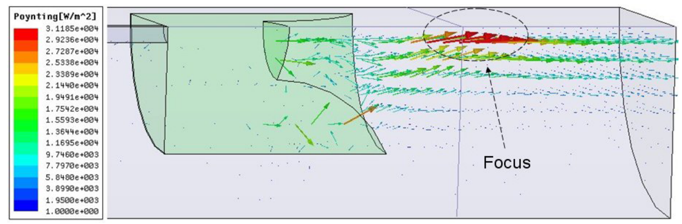

Fig. 2: Simulated Poynting vector plot and the focus point.

Several lenses have been fabricated, as shown in Fig. 3, from Delrin (ε_r = 3.8), silicon (ε_r = 11.7) and Macor (ε_r = 5.7) with diameters (D) of 8 cm, 2.8 cm and 1.8 cm, respectively. A number of measurement and characterization possibilities implementing frequency-domain and time-domain techniques using a Vector Network Analyzer have been considered. Several antennas have been designed and fabricated. The lenses, being coupled to an antenna or a waveguide, can be characterized by a suitable method, e.g. near-field probing, backscattering etc.

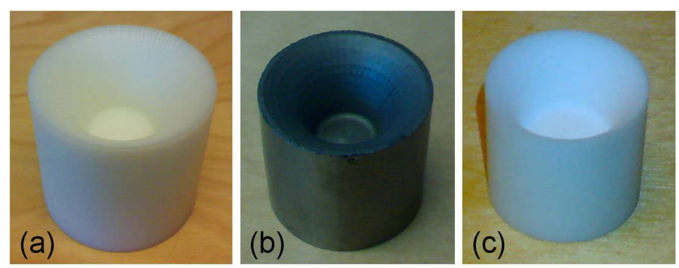

Fig. 3: Fabricated catadioptric dielectric lenses (a) Delrin, D = 8 cm (b) silicon, D = 2.8 cm and (c) Macor, D = 1.8 cm.

In this paper, we present preliminary measurement and characterization results of the catadioptric dielectric lens at WR22 (33 GHz – 50 GHz) frequencies.

II. RESULTS

The catadioptric lens made of Delrin, shown in Fig. 3 (a), was characterized. In order to attain intense focusing using the catadioptric lens, it is necessary to feed the lens with such a source so that the coupled mode facilitates the creation of the focus. In the mmw frequencies one option to feed the lens is to use an open ended waveguide with a tapered dielectric section inserted at the end. This kind of setup reduces reflection loss introduced by the lens. For the current and preliminary investigation, a horn antenna was used. The lens-horn antenna configuration shows good performance in terms of return loss. However, the aperture of the horn antenna and the coupling to the lens is not ideal for obtaining intense focus. Nevertheless,

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the broadband performance of the lens-horn antenna configuration provides greater ease to determine the focus around a specific frequency.

The lenses, fabricated from Macor and silicon, were not used in this preliminary investigation due to their higher dielectric constants and smaller dimensions compared to the aperture of the WR22 horn antenna. The higher dielectric constants of the lens introduce higher reflection losses. The catadioptric lens made of Delrin, showed in Fig. 3 (a), was used. The diameter of the lens is 8 cm and ε_r = 3.8. At 40 GHz, the diameter of the lens is ~ 10 $\lambda_{freespace}$ or ~ 20 λ_{lens}.

In contrast to other more accurate methods, a simple qualitative approach was followed where 1 port measurements were performed using a HP 8510C VNA. The VNA was calibrated with 2.4 mm calibration kit and measurements were performed from between 33 GHz to 43 GHz. However, the return loss performance of the lens-horn antenna is most satisfactory from 40 GHz to 43 GHz and therefore the uncertainties in determining the amount of reflected power are less compared to other frequencies. Moreover, the focusing of the lens is frequency dependent and it was experimentally observed that the lens focuses more prominently at the afore-mentioned band compared to other investigated frequencies.

A 10 SEK metal coin (diameter = 2 cm) was placed in front of the lens-antenna at different cocentric positions ranging from Z = 0 cm to 10 cm with 0.5 cm steps. Here, Z denotes the distance of the coin from the facet of the lens. Fig. 4 shows the lens, antenna and the coin.

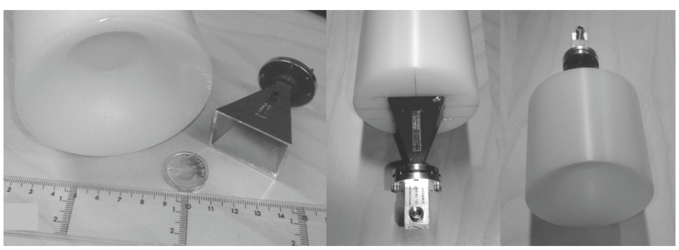

Fig. 4: The catadioptric dielectric lens, WR22 horn antenna and the 10 SEK coin, used for backscattering measurements.

The main approach of this characterization setup was to determine the amount of power reflected by the coin at different Z positions. If there is no focus, the reflected power would roll off with Z. On the other hand, a focus perturbs the roll-off profile of the reflected power.

The S_{11} parameters, obtained by the 1 port measurements, were converted into time domain by inverse Fourier transformation and the amplitude of the reflected signal was investigated in time domain. Fig. 5 shows the amplitude of the reflected signal at different positions. The maxima of the reflected signals at different positions correspond to the positions of the coin in along Z direction. For instance, the maxima of the reflected signals for Z = 0 cm and Z = 0.5 cm are 0.033 ns apart. This translates to a total distance of 1.0 cm which includes 0.5 cm distance of travel in forward direction and another 0.5 cm distance of travel in the backward direction.

As can be seen in the Fig. 5, when the coin is placed at relatively farther position the reflected amplitude scales with the distance. However, a focus can be observed between Z = 0.5 cm and 1.0 cm where the amplitude of the reflected signal is even higher than that of Z = 0 cm. Therefore, the figure provides qualitative information regarding the focus of the catadioptric lens.

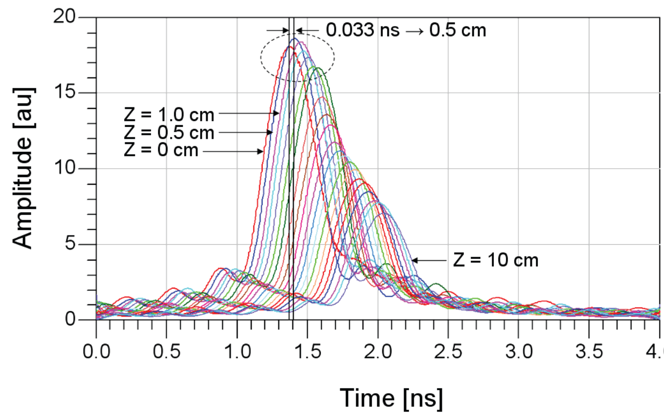

Fig. 5: Reflected signals by the coin at different Z positions in time domain, obtained by inverse Fourier transformation of S_{11} parameters from 40 GHz to 43 GHz.

III. Conclusion

Preliminary measurements results of a catadioptric lens have been presented in the mmw frequencies. A simple qualitative approach was used where the focus was determined by backscattering method. However, a more accurate and quantitative approach would be to probe the nearfield with a monopole or dipole having negligible dimension along with a power meter. Our future investigations include quantitative characterization of the lenses from 5 GHz to 100 GHz, determining the focus depth and its spatial discrimination, and using the lenses in imaging setups using both forward and inverse scattering methods.

Acknowledgement

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